PROC. R. SOC. VICT. vol. 100, 53-59, October 1988

EFFECTS OF EDUCTOR DREDGING OF GOLD TAILINGS ON AQUATIC ENVIRONMENTS IN VICTORIA

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Abstract: Information on the effects of eductor (suction) dredging on Victoria's aquatic habitats and organisms is reviewed and discussed. The paucity of information makes a rational assessment impossible and highlights the need for relevant studies in Victoria. Evidence from North American studies suggests that the rate at which benthic invertebrate communities recover depends on the distance between the dredge site and an undisturbed source of invertebrates upstream. In only one North American study has the effect of passage of fish eggs and fry through an eductor dredge been examined. Alteration of benthic habitat by deposition of sediment downstream from eductor dredging can influence the species composition, diversity and biomass of aquatic communities.

Eductor dredges are small hydraulic suction devices used to recover alluvial sediments containing gold from rivers and streams. Escalation of gold prices in recent years has contributed to an increase in eductor dredging in Victorian waterways—particularly in catchments renowned for gold mining. Since the 1970s, eductor dredges have become popular with both professional and hobby gold seekers. Annual licences permitting the use of eductor dredges have been issued in Victoria since 1979, but the number of dredges operating each year in Victorian waterways may be 1200 more than the number of licences issued (CFL 1986). Despite the increased eductor dredging and widespread concern about its effect on the aquatic environment, studies have been few. In this paper I review the available literature on the impact of eductor dredging on aquatic habitats, and discuss the possible effects of eductor dredging on some of Victoria's waterways.

Operation of eductor dredges

Eductor dredges consist of a high pressure pump driven by a small petrol engine which feeds a jet of water past an eductor or venturi and so provides suction along the intake pipe (Bell 1983, Doeg 1985). The intake pipe (up to 150 mm diameter) is passed over the streambed and lifts sediment to a floating barge. Material collected is passed over a sluice box which traps the heavier particles and the unwanted "lighter" material is discharged directly from the rear (downstream) of the barge. Barges are of two main types: a moored barge—from which the discharged material is localised; and a mobile barge which follows the position of the diver/operator. Sediment from the latter barge is distributed in an unconsolidated state over a broad area. Dredging effects referred to in this paper are derived primarily from studies of dredges on mobile barges.

Intake pipes can be blocked by large objects, so the common practice is to move rocks and other large objects to the sides of a streambed or to other instream areas to reduce current velocities prior to dredging. Operators rarely replace rocks after dredging.

The depth of sediment disturbed by dredging varies from 60 cm to more than 200 cm. In the section of stream being worked, the area of a streambed dredged has increased from 10-15% during 1979-80 to as much as 100% during recent years (CFL 1986). The area over which discharged sediment is distributed downstream of the dredge site depends mainly on the size of sedimentary particles, water velocity and the type of stream.

Most of the eductor dredging in Victorian streams is carried out during summer and autumn when water temperatures are highest and water levels are lowest.

INSTREAM EFFECTS AT SITE OF DREDGING

Damage to Physical Habitat

Relocation of large objects: The removal of rocks, stones or wood debris, too large to pass through dredge intake pipes, from a stream before or during dredging results in the loss of 'shelter' habitat for instream organisms. Large instream objects are invariably the most resistant to shear stress caused by flowing water, and provide stable shelter for organisms. Hynes (1970) stressed the importance of such objects in causing local variation in current speed which in turn results in mosaic distributions of animals. Although the distribution of most invertebrates can be expected to change seasonally with changes in discharge volumes, the diversity, and to a lesser extent the biomass, of invertebrates is largely determined by the existence of these impediments to flow (Hynes 1970).

Studies overseas have shown that depletion of habitat diversity (i.e., removal of instream objects) combined with a reduction in substrate stability result in a reduction in the abundance and diversity of benthic and drifting macroinvertebrates (Etnier 1972, Arner *et al.* 1976, Bulkey *et al.* 1976, Schmal & Sanders 1978, Zimmer & Bachmann 1978). In the only Australian study, Hortle and Lake (1982) did not detect significant and consistent differences in species richness, density and standing crop of macroinvertebrates between channelised and unchannelised sections of the Bunyip River, Victoria. They attributed this finding to the restoration of adequate habitat diversity and substratum stability during the period between channelisation and the investigations.

Instream rocks are also important in the life cycles of many fishes. Up to 75% of Victoria's native species of freshwater fish deposit their demersal eggs on or near large rocks or other large submerged objects (Table 1) (Cadwallader & Backhouse 1983). More than 50% of these species spawn during November-March (Table 1)—a time which coincides with the most active period for eductor dredging. There are no reports on the survival of fish eggs in Victorian streams after such relocation of 'harbour' objects, nor on any long-term effects this practice may have on the abundance or diversity of fish in a stream subjected to eductor dredging.

Large submerged objects provide important habitat for many native fish during post-embryonic stages of their life cycles. Small tupong (*Pseudaphrites urvilli*) are often found amongst large, instream rocks, and adults of the species are often associated with submerged logs and other objects which provide shelter (Cadwallader & Backhouse 1983). River blackfish (*Gadopsis marmoratus*) are usually found in hollow logs or under stones, and the broad-finned galaxias (*Galaxias brevipinnis*), which characteristically inhabit steep, fast-flowing streams, usually live amongst large rocks or under logs (Cadwallader & Backhouse 1983). Recent studies on the habitat preferences of native freshwater fishes indicate that many species use submerged objects for daily, intermittent or seasonal shelter (Fisheries Division, unpublished data).

Results from studies overseas have implicated removal of instream objects as a cause of the reduction in the standing crop, numerical density and diversity of resident fish assemblages after "river improvements" (Duval *et al.* 1976, Moyle 1976, Marzolf 1978, Schoof 1980). Hortle and Lake (1983) found a positive correlation between habitat diversity (i.e. maintenance of instream objects) and the total numbers, biomass and species richness of fish assemblages in the Bunyip River, Victoria.

In Victoria, eductor dredging takes place during summer and autumn; therefore rocks and stones moved by dredge operators are probably redistributed during subsequent flood or high-flow events. Fishes would probably move to adjacent suitable habitat during pre-dredging and dredging activities and might return when the instream conditions improved. However the intensity of eductor dredging in some of Victoria's waterways may be such that the instream habitats and the fish populations may be unable to recover, especially considering the proposals to further regulate flow in streams where eductor dredging is currently practised. Furthermore, the timing of dredging may directly coincide with critical life history stages of the organisms dependent on the area to be dredged.

Alteration of streambed substrate and profile: The effect of eductor dredging on the physical environmen at the site of dredging involves removal of sedimen of small particle sizes and re-sorting of the large material. The depth of substratum affected depend on the intensity of the dredge operation, and in recen years commonly extends as much as 200 cm down t bedrock. By its very nature, eductor dredging modifies the substrate to the extent that the dredged substrate consists of particles of larger mean size that ar less compacted.

Griffith and Andrews (1981) dredged five sampl plots of 0.25 m^2 to a depth of 15 cm during summer The plots had a depauperate benthic macroinvertebrate fauna immediately after dredging, but th numbers of individuals had recovered to 90% of th original number within 38 d. After 38 d, species composition and relative abundance of the major taxa a the dredged sites were the same as those of adjacen undredged sites. They suggested that recolonisatio might occur more slowly during other seasons and—more pertinently—if larger areas were disturbed b dredging. Minshall (cited by Griffith & Andrews, 1981 related the rate of recolonisation to the distanc between the dredge site and a source of invertebrate upstream. One dredged site on the Teton Rive (Idaho), 50 m downstream from an undisturbed section, took 90 d to recolonize, whereas another, locate 5.5 km below the source, took 439 d. Griffith an Andrews (1981) also describe other, as yet uninvestigated, impacts of eductor dredging—for example th trampling of aquatic organisms by dredge operators

The only other study of effects on fauna at th dredging site was conducted also during summer b Harvey (1986), who investigated the impact of a singl dredge at a site of unspecified dimensions and th cumulative effect of several dredges in a limited defined area. In neither case did he specify the dept of dredging nor the size of dredged plots. He did find however, that dredging affected the composition an relative abundance of benthic invertebrate species— change he attributed directly to substrate alteration Harvey found that the species assemblage at th dredged site returned to its pre-dredged compositio within 45 d.

Another effect of intensive dredging in localize areas is the creation of "mountain and crater" topography of the streambed near the dredge site. The creation of craters in sections of streams containing fe pools could provide valuable fish habitat and migh contribute to a local increase in the carrying capacit of that section of the stream.

Finally, McCleneghan and Johnson (1983) note that the common practice by American dredge operators of undercutting stream banks can destabilise th banks causing further erosion and course change during high flows. This erosion can also lead to de truction of riparian vegetation and habitat.

Damage to Entrained Organisms

Eductor dredging removes benthic biota and passe them and the associated sediment through the dredg apparatus. This has an immediate impact on the composition of the remaining benthic environment and on the composition and quality of the discharged material.

Griffith and Andrews (1981) evaluated the effects of passage through a small eductor dredge (30 cm sec^{-1} intake velocity; intake pipe 76 mm diameter) of aquatic invertebrates and fish in four small streams in Idaho. They dredged to a depth of 15 cm and reported that fewer than 1% of the benthic invertebrates that passed through the dredge were severely injured or died within 24 h. Most of the dead specimens belonged to one genus of mayfly undergoing emergence at the time of dredging; their deaths were attributed to the sensitive nature of the organisms at this critical life history stage. Griffiths and Andrews (1981) suggested from their results that adult invertebrates are surprisingly resistant to damage from entrainment and that only those insects at the emergent stage are at risk.

Bell (1982) reported that gross damage to invertebrates entrained by an eductor dredge in a Victorian stream was not significantly different to that of undredged samples transported to the laboratory in buckets containing unsorted sediment. The high proportions of damaged invertebrates in undredged samples are most probably the result of damage by sediment during transportation in buckets. This probably masked any effects attributable to dredge entrainment.

The effects of entrainment on fish eggs and larvae have been investigated only by Griffith and Andrews (1981). They found that all the uneyed eggs of cutthroat trout (*Salmo clarkii*) died within 5 minutes of entrainment because of ruptured vitelline membranes; natural mortality was only 35% after 36 h. Mortality in eyed hatchery rainbow trout (*Salmo gairdini*) that had passed through a dredge was similar to that of non-dredged specimens over 10 d. Mortality of sac fry of rainbow trout that had passed through the dredge was 83% compared to 9% for the controls. The main cause of death was detachment of the yolk sac from the body of the fry. Griffith and Andrews (1981) presumed that all fish larger than sac fry were sufficiently mobile to avoid the intake pipe. They made no attempt to investigate survival of viable eggs and larvae removed from the habitat in which they naturally occurred and subsequently scattered downstream from the dredge.

No comparable studies on the effects of dredging have been conducted on Victorian species of fish at different stages of their life cycle, but disturbance of the substrate would probably affect the survival of species that utilise this habitat at early stages of their life cycle. Larval short-headed lampreys (*Mordacia mordax*) burrow into the sediment for the early part of their life (Potter 1970), and the river blackfish, Australian grayling (*Prototroctes maraena*), native *Galaxias*, gudgeons and other fish species deposit eggs over the substrate (Table 1).

INSTREAM EFFECTS DOWNSTREAM FROM DREDGE SITES

Survival of Entrained Fauna

The distances that entrained organisms and sedimentary material are carried downstream from the dredge site depends on their mass and prevailing current conditions. Survival of those organisms unaffected by passage through the dredge depends on successful translocation and subsequent deposition in suitable habitat. Bell (1982) reported that Victorian dredge operators often saw organisms such as freshwater crayfish, redfin (*Perca fluviatilis*) and brown trout (*Salmo trutta*) feeding in the wash from the dredges. In that way eductor dredging may increase predation of entrained organisms.

The physical and biological composition of the streambed exerts considerable influence on the survival of benthic organisms. Under natural conditions benthic organisms are distributed in mosaic assemblages according to prevailing environmental conditions. Redistribution of entrained organisms to suitable habitats by eductor dredging is a chance phenomenon which has not been investigated. Organisms capable of actively seeking suitable habitat whilst drifting or after being deposited (ie., mobile invertebrates) (Pearson & Jones 1975) could be expected to have higher survival rates than more sedentary taxa or life stages (e.g., fish eggs).

Alteration of Benthic Habitat by Deposition of Sediment

Deposition of sediment downstream from eductor dredging can alter streambed characteristics. Recent studies of sedimentation in streams have consistently shown dramatic changes in species composition, diversity and total numbers of invertebrates attributed to the effects of physical abrasion of organisms by suspended sediment, smothering of suitable habitat, reduction in the capacity of smothered areas to produce food organisms and the alteration of behavioural responses like drift (Chutter 1969, Hynes 1970, Cordone & Kelly 1971, Nuttall & Bielby 1973, White & Gammon 1977, Crouse *et al.* 1981, Harvey *et al.* 1982, Blyth *et al.* 1984, Harvey 1986). Luedtke and Brusven (1976) concluded that the deposition of fine, loosely-compacted sediments, combined with prevailing downstream currents, severely impairs the ability of benthic invertebrates to migrate upstream. The short-term and long-term effects of this type of disturbance depend on the species composition of affected areas and the ability of those organisms, and others from adjacent areas, to adjust to the modified environment. Moreover, indiscriminate relocation of gravel and rocks could create barriers to fish and invertebrate migration by blocking streams or increasing subsurface percolation such that surface flows are severely restricted or non-existent.

Bell (1982) deduced that sediments disturbed by a single dredge operating in Gaffneys Creek (Victoria) had only localised impact downstream, and that the

TABLE 1

SPAWNING SEASON AND EGG CHARACTERISTICS FOR NATIVE FRESHWATER FISH FOUND IN VICTORIA. (Su = summer; Au = autumn; Wi = winter; Sp = spring.)

Common name	Scientific name	Spawning season	Egg type
Short-headed lamprey	*Mordacia mordax*	Sp/Su	Demersal
Pouched lamprey	*Geotria australis*	⋆	Demersal
Short-finned eel	*Anguilla australis*	⋆	⋆
Long-finned eel	*Anguilla reinhardtii*	⋆	⋆
Freshwater herring	*Potamalosa richmondia*	⋆	⋆
Bony bream	*Nematalosa erebi*	Sp/Su	⋆
Common galaxias	*Galaxias maculatus*	⋆	⋆
Flat-headed galaxias	*Galaxias rostratus*	⋆	Demersal
Mountain galaxias	*Galaxias olidus*	Wi/Sp/Su	Demersal
Broad-finned galaxias	*Galaxias brevipinnis*	Au/Wi	Demersal
Spotted galaxias	*Galaxias truttaceous*	Au/Wi	Demersal
Dwarf galaxias	*Galaxiella pusilla*	Wi/Sp	Demersal
Australian smelt	*Retropinna semoni*	Sp	Demersal
Australian grayling	*Prototroctes maraena*	Su/Au	Demersal
Freshwater catfish	*Tandanus tandanus*	Sp/Su/Au	Demersal
Crimson-spotted rainbowfish	*Melanotaenia splendida*	Sp/Su	Demersal
Small-mouthed hardyhead	*Atherinosoma microstoma*	Sp/Su	⋆
Freshwater hardyhead	*Craterocephalus stercusmuscarum*	Sp/Su	Demersal
Lake Eyre hardyhead	*Craterocephalus eyresii*	Su/Au	Demersal
Murray cod	*Maccullochella peeli*	Sp/Su	Demersal
Trout cod	*Maccullochella macquariensis*	Sp/Su	Demersal
Macquarie perch	*Macquaria australasica*	Sp/Su	Demersal
Golden perch	*Macquaria ambiqua*	Sp/Su	Buoyant
Silver perch	*Bidyanus bidyanus*	Sp/Su	Buoyant
Southern pigmy perch	*Nannoperca australis*	Wi/Sp	Demersal
Yarra pigmy perch	*Edelia obscura*	Sp	Demersal
Freshwater blackfish	*Gadopsis marmoratus*	Sp/Su	Demersal
Tupong	*Pseudaphritis urvilli*	Au/Wi	⋆
Striped gudgeon	*Gobiomorphus australis*	Su	Demersal
Cox's gudgeon	*Gobiomorphus coxii*	⋆	Demersal
Flat-headed gudgeon	*Philypnodon grandiceps*	Sp/Su	Demersal
Purple-spotted gudgeon	*Mogurnda adspersa*	Su	Demersal
Western Carp gudgeon	*Hypseleotris klunzingeri*	Sp/Su	Demersal

⋆ denotes unknown characteristics or estuarine phases of life cycle.

quantities of sediment suspended were similar to those recorded after rain. The sediment load however, occurred at a time uncharacteristic of normal weather and streamflow patterns.

Doeg (1985) suggested that a more realistic assessment of dredge effects would be gained from examination of the faunal composition of larger areas of streams known to be subject to dredging, and to compare results obtained with those from a nearby stream that was not subject to dredging. To this end Doeg (1985) sampled seventeen 0.3 m sites in riffle sections of five tributaries of Lake Eildon. Sites were kick sampled to a depth of 10 cm during winter. Unfortunately, Doeg (1985) collected no samples during summer and autumn, the seasons of intensive dredging, nor did he collect samples from slow-water habitats where most suspended sediment would be expected to settle, nor samples from areas downstream from eductor dredge sites before and after dredge operations. Thus any impact of previous dredging could have been masked by seasonal changes in, or alterations to, community structure resulting from other environmental influences, or both. Subsequent community analysis by ordination and classification techniques grouped samples according to broad patterns of similarity, but did not allow an objective and quantitative assessment of any changes resulting from eductor dredge operations.

The effects of sediment deposition on fish production in streams has been investigated in several overseas studies. Sedimentation can affect fish assemblages by decreasing survival of embryos (Cooper 1965), by reducing rearing and reproductive habitat for juvenile and adult fish (Bjornn *et al.* 1977, Berkman & Rabeni 1987) and by reducing the stream's capacity to produce food organisms (Phillips 1971, Berkman & Rabeni 1987). Berkman and Rabeni (1987), in a study of the effects of siltation on stream fish communities in Missouri, noted a reduction in the numbers of species of benthic insectivorous and herbivorous fish and also species that required a clean gravel substrate for spawning. Crouse *et al.* (1981) found that sedimentation suppressed production of coho salmon

(*Oncorhynchus kisutch*) by destroying spawning and rearing habitats. Saunders and Smith (1965) attributed low standing crops of brook trout (*Salvelius fontinalis*), in a Canadian stream subject to siltation, to the destruction of hiding places. Turnpenny and Williams (1980) attributed declines in the abundance of brown trout, in aWelsh stream carrying suspended sediment, to the smothering of eggs during incubation in the substrate. Whilst the study by Turnpenny and Williams is not directly applicable to trout abundance in Victorian streams, the findings may have relevance to declines in the abundance of native fish species which lay eggs on the substrate during summer and autumn.

Increased sediment loads in coastal rivers and streams can affect the physical and biotic environments of receiving waters. Salinity-induced flocculation generally leads to precipitation of suspended sediments in estuarine waters. These processes are considered to have contributed to the recent die-back of seagrass in Western Port and the consequent decline of the commercial fishery (WPCCG 1983, C. M. MacDonald pers. comm.). Morgan (1986) has reported evidence of a recent seagrass decline in Corner Inlet. Hall and MacDonald (1986) have emphasised that sedimentation from coastal catchments poses one of the single greatest threats to the future production of Victoria's bay and inlet fisheries. Countenance of any activities contributing increased sediment loads to coastal rivers must give due consideration to their possible effects on coastal environments.

Mobilisation of Chemicals

Eductor dredging is commonly conducted in sections of streams where concentrations of mercury in sediments are high because mercury has been used in the past to extract gold (Bell 1982). During a study in the upper reaches of the Goulburn River, McCredie (1982) found that mercury is concentrated in the finer sedimentary fractions and is readily redistributed to aquatic ecosystems by activities such as eductor dredging. But Ealey *et al.* (1983) found that although mercury concentrations were elevated in benthic invertebrates in Raspberry Creek, there was little evidence of a significant effect on the composition of aquatic benthic communities. Results from both studies revealed elevated mercury concentrations in fish throughout the study area in the upper reaches of the Goulburn River.

TABLE 2
COMPOUNDS FOUND IN AURIFEROUS ZONES IN VICTORIA
(Glover *et al.* 1980).

Element	Form
Antimony	stibnite (antimony sulphide) bournonite (sulphide of copper, lead and antimony)
Arsenic	arsenopyrite and arsenic trioxide
Cobalt	associated with nickel
Copper	elemental and calcopyrite (iron copper sulphide)
Chromium	chromite (iron chromate)
Iron	pyrite (iron sulphide)
Lead	associated with gold, pyrite, arsenopyrite bornite, blende, cerussite, pyromorphite, hydrated oxides and carbonates in association with malachite and azurite and limonite
Manganese	haematite and manganese oxide
Nickel	associated with cobalt
Silver	alloy with gold as a chloride and in association with lead antimony sulphide
Tungsten	iron and manganese tungstate and calcium tungstate
Zinc	zinc sulphide
Thorium	thorium
Platinum	platinum

A thorough review of the available information on the incidence and effect of mercury in stretches of Victorian streams utilised for eductor dredging has been given by Bacher (1987). While a comprehensive study of other metals and compounds has not been performed, Glover *et al.* (1980) reported the potentially harmful compounds in sediments below auriferous zones (Table 2), any or all of which could be mobilised by eductor dredging. Recent advances overseas in behavioural toxicity testing of fish have shown sublethal exposure to various metals and metal compounds can alter certain behaviours such as avoidance reactions, feeding behaviour, learning, social interactions and a variety of locomotor behaviours (Atchison *et al.* 1987). Such behavioural perturbations can affect fish populations at sublethal concentrations of contaminants.

The potential for fuel and oil spills from eductor dredges has not been addressed in any studies conducted to date.

CONCLUSIONS

Eductor dredging affects the physical environment of streams by removing fine sediments from the site of dredging and subsequently redistributing them downstream. Because most of the available literature concerning the biological effects of such operations relates to overseas studies on particular organisms or groups of organisms, the effects of eductor dredging on the Victorian environment are impossible to assess. Whilst it is most probable that the nature and extent of the present eductor dredge practices in Victorian streams are causing relatively localised disruptions to stream ecosystems, the short- and long-term effects of eductor dredging will be elucidated only from well-designed studies. Ultimately, resolution of the environmental debate concerning eductor dredging will depend on the results of these studies.

ACKNOWLEDGEMENTS

I am grateful to Darwin Evans and Jim Pribble for useful comments on an earlier version of this manuscript.

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